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In search of sustainable livestock management in the Dry Chaco: effect of different shrub-removal practices on vegetation

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ABSTRACT

Increasing shrub density hinders cattle raising in central Argentina rangelands. While roller-chopping and hand-cutting are used to remove shrubs and make land accessible for cattle grazing, studies on the effects of these practices on ecosystem composition, structure and functioning are scarce. We assessed the impact of shrub removal on (a) vegetation cover, composition, species richness and diversity and (b) green biomass and seasonal phenological dynamics. We used a randomised design with three treatments (degraded rangeland; roller-chopping and hand-cutting) with four replicates, and compared the treatments with the least disturbed woodland (conserved woodland). *Cenchrus ciliaris* L. was sown following removal treatments and grass cover increased significantly (45% roller-chopping and 84% hand-cutting vs 27% degraded rangeland, and 13% conserved woodland), and tree cover decreased (3% roller-chopping and 2% hand-cutting vs 16% degraded rangeland, and 23% conserved woodland). Shrub cover reached 45% under roller-chopping, similar to the degraded rangeland treatment (46% degraded rangeland, 60% conserved woodland), but in hand-cutting reached only 3% cover. Hand-cutting reduced species richness and vegetation diversity, whereas roller-chopping had no effect. Shrub-removal treatments decreased normalised difference vegetation index (NDVI; *proxy* of green biomass) and modified ecosystem phenology. Under both shrub treatments, the maximum, minimum and integral NDVI (area under the NDVI curve) were significantly lower than those of the degraded rangeland treatment. The results suggest that shrub-removal practices increase forage for livestock, but reduce functional diversity and compromise the return to less disturbed states (woodland), where tree populations are maintained.

Keywords: biomass production, disturbance, extensive grazing systems, grazing, rangeland management, shrublands, woodlands, woody-plant encroachment.

Introduction

Shrub encroachment on natural rangelands is a worldwide concern for ecosystem functioning documented in America, Australia and Africa (Archer 2010; Rejžek *et al.* 2017; Chandregowda *et al.* 2018). The main causes of encroachment include climate change, overgrazing, seed dissemination by livestock, reduced fire frequency, reduced competition with grasses and increased atmospheric CO_2 (Van Auken 2000). Consequences include decreased forage grass cover and an increased erosion (Eldridge *et al.* 2011). Thus, in the absence of shrub treatment, thresholds could be reached where vegetation and soil changes persist (Willcox and Giuliano 2010; Bestelmeyer *et al.* 2015).

In North America, shrub-encroachment rates range from ~0.2% cover per year in the Sagebrush Steppe region to 1.6% in the Central Great Plains. In semi-arid regions, shrub encroachment may contribute to increased aboveground net primary production (Barger *et al.* 2011). In Argentina, the 'shrub eradication paradigm' has led to the application of various methods to eliminate shrubs, but in so doing it has also damaged tree populations. In this sense, the development of cattle ranching in the Chaco region brought with it production models designed for regions with different agro-ecological conditions (e.g. the Pampean region), where disturbances aim to create homogeneous, shrub-free grasslands (Navall 2008). Elsewhere, the increase in grasses after disturbance has been shown to suppress tree seedling establishment, but also to increase the growth of remaining large trees (Monegi *et al.* 2022).

In the central arid region of Argentina, shrub encroachment is a consequence of severe overgrazing and logging of woodlands, particularly in the flat region of the province of La Rioja (Dry Chaco) where the economy is now based on extensive cattle and goat farming (Blanco *et al.* 2005; Calella and Corzo 2006). For several decades, this region was intensely logged, causing woodland degradation (Natenzon and Olivera 1994).

The transformation of rangelands into dense shrublands reduced forage supply and domestic livestock accessibility (Kunst *et al.* 2012). Although shrubs compete with grasses for resources, mainly water and light, and impede animal movement (Kunst *et al.* 2003; Blanco *et al.* 2005), they are fundamental in regulating systems, such as water and carbon cycles (Huxman *et al.* 2005; Magliano 2016; Nosetto *et al.* 2020), spatial heterogeneity (Villagra 2000), soil nutrient supply (Anriquez *et al.* 2005; Pérez Harguindeguy *et al.* 2022), and habitat preservation for fauna (Szymañski *et al.* 2021). A significant proportion of shrub species contribute to forage (Allegretti *et al.* 2012; Egea *et al.* 2014); so, strategies seeking to maximise livestock production through shrub removal can conflict with those promoting conservation of native vegetation and provision of other ecosystem services. However, new trends in sustainable woodland management aim to integrate both these approaches (Villagra and Alvarez 2019).

In the past two decades, Dry Chaco rangers have sought to increase forage production by removing shrubs mechanically with a roller-chopper, or by hand, and by sowing with exotic pasture species (Marchesini 2011; Rueda *et al.* 2013; Kunst *et al.* 2016). Roller-chopping is performed with a heavy, cylindrical machine and pulled by a tractor, which crushes and cuts vegetation (Kunst *et al.* 2003). It may also distribute seeds of exotic forage species such as *Cenchrus ciliaris* and *Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs (Anriquez *et al.* 2005; Marchesini 2011). Hand-cutting generally involves greater removal of woody biomass (Kunst *et al.* 2016), is undertaken with hand-tools such as pick, axe and shovel, and generally removes shrubs at the root. Neither practice is selective, so saplings are removed and few mature specimens retained to provide livestock shade (Nai Bregaglio *et al.* 2001). Such transitions reduce biodiversity, alter soil nutrient cycles and the rate of litter decomposition, and reduce carbon storage (Villarino *et al.* 2017; Pérez Harguindeguy *et al.* 2022; Lizzi and Garbulsky 2023).

In degraded rangelands of central Argentina, regional studies have focused on effects on grass productivity (Blanco *et al.* 2005; Kunst *et al.* 2016). Studies of vegetation structural and functional attributes, especially the woody stratum, are scarce (Rejžek *et al.* 2017). Therefore, our aim was to evaluate two types of shrub removal (mechanical = roller-chopping and hand-cutting) in degraded rangeland on (a) vegetation cover, composition, species richness and diversity, and (b) green biomass and its seasonal dynamics. We also compared these treatments with less disturbed woodlands because they are considered the desired state from a conservation and livestock production viewpoint.

We tested the following predictions: the normalised difference vegetation index (NDVI), as a *proxy* of green biomass, and vegetation diversity, as characterised by species cover, species richness and the Shannon diversity index, will be lower and have greater seasonal variability on sites with shrub removal than where shrubs have been retained. Furthermore, these effects are expected to be more pronounced under manual removal treatment than with mechanical removal.

Materials and methods

Study area

The study was conducted in the Southern Plains of La Rioja province of Argentina (30°30′S, 66°07′E; Calella and Corzo 2006) within the biogeographic district of the Dry Chaco (Ragonese and Castiglioni 1968; Fig. 1). The weather is monsoonal, with mean annual precipitation of 387 mm (1979–2018). The rainfall is seasonal (82% between November and March), with a high annual variability. Maximum temperatures occur between November and January, and minimums between May and July. The average annual temperature is 20°C (Blanco 2017). The landscape has three distinct vegetation strata (tree, shrub and herbaceous). Tree density is low and species form mixed stands of *Aspidosperma quebracho-blanco* (Schltdl), *Prosopis flexuosa* (DC.) and *P. torquata* (Cav. ex Lag.) DC. The shrub layer is dense, with dominant species including *Larrea divaricata* (Cav.) and *Mimozyganthus carinatus* (Griseb.) Burkart and the herbaceous stratum is generally sparse as a consequence of high grazing pressure. The most frequent grass species are *Leptochloa crinita* (Lag.) P.M. Peterson & N.W.Snow, *Gouinia paraguayensis* (Kuntze) Parodi, *Digitaría califórnica* (Benth.) Henrard, and *Setaria pampeana* Parodi ex Nicora (Biurrun *et al.* 2015).

Study design

Field sampling and remote-sensing analysis was conducted on sites with and without mechanical and manual shrub removal. Sites were distributed in environmentally homogeneous areas according to satellite image analysis. In addition,

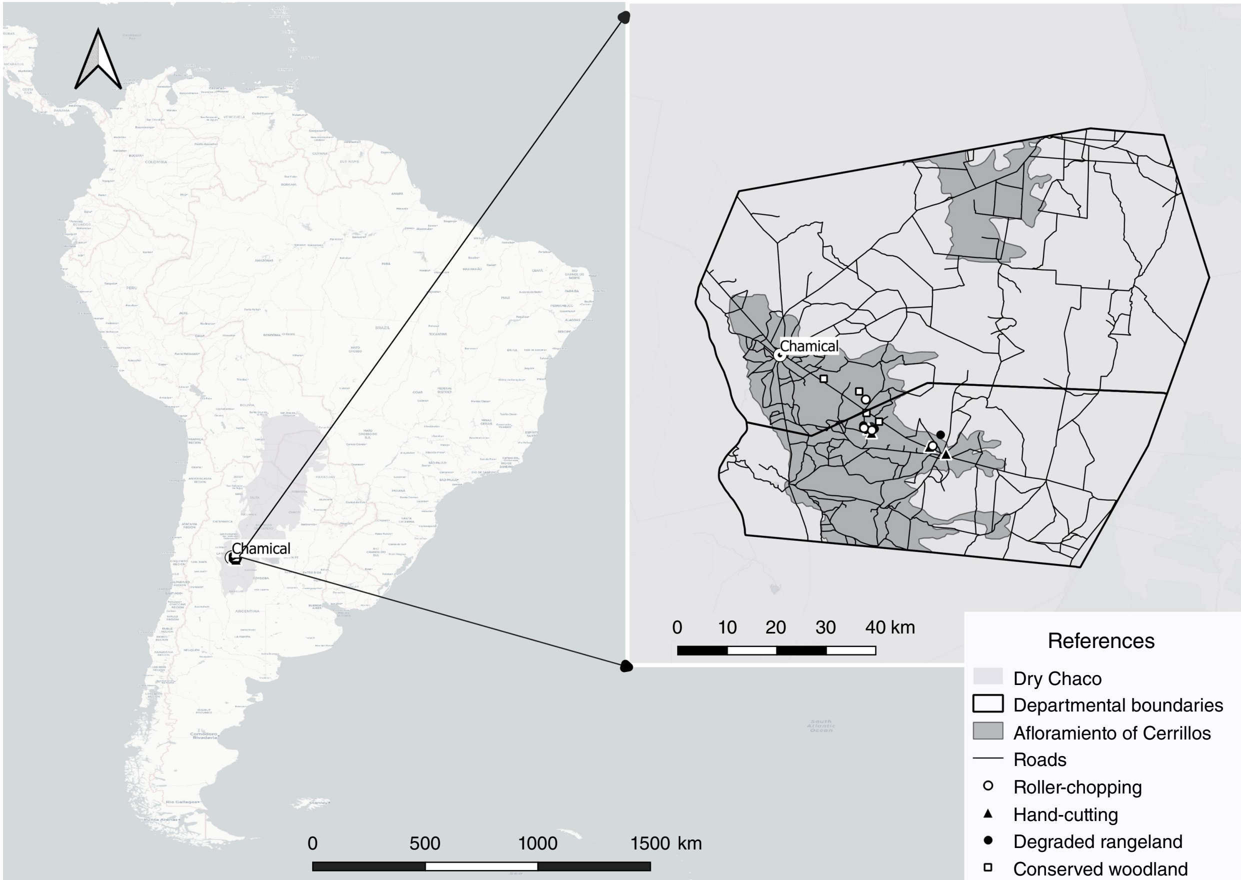

Fig. 1. Location of the study site in rangelands of central Argentina in the south of the province of La Rioja.

the region's less disturbed woodland ('conserved woodland'), considered a reference ecosystem from a structural and functional point of view (Villagra and Alvarez 2019), was also sampled. These sites were not logged in past decades and are currently grazed with cattle at low stocking rates. A completely randomised design with three treatments and four replicates was established. The treatments were as follows: degraded rangeland with shrub retained (hereafter 'degraded rangeland'); degraded rangeland with mechanical shrub removal using a roller-chopper ('roller-chopping'); and degraded rangeland with hand-cutting shrub control ('hand-cutting'). Shrub-removal treatments were seeded with the exotic species *Cenchrus ciliaris* variety Texas 4464.

Plots were not sampled prior to the application of treatments. Six years after the shrub-removal treatments had been applied, the modified point-quadrat method, was used to determine the richness and total and specific vegetation cover of trees, shrubs, grasses and forbs (Passera *et al.* 1983). We randomly located three 50 m line transects at each site, avoiding proximity to wire fences or cattle trails. A 2 m rod placed vertically at 0.5 m intervals along each transect (100 points) was used to assess vegetation interception. At each location and along each line, the composition and the number of species (richness) were recorded and the cover was estimated as the percentage of points intercepted by each species. Measurements were taken in March–April 2019 at the end of the growing season. Using plant species cover data, we calculated the Shannon and Weaver (1949) index using the following formula:

$$H = -\sum \mathrm{Pi} \times \ln \mathrm{Pi}$$

H = Shannon–Weaver diversity index,
Pi = the proportion of the total coverage represented by the coverage of each species, and
ln = log base$_n$

Raunkiaer's (1934) classification of bioforms was used as a criterion for grouping the recorded species into functional groups and scientific names were corroborated in the Darwinion Botanical Institute database (http://www.darwin.edu.ar/).

We used the NDVI as a *proxy* of green biomass (Paruelo *et al.* 1997). NDVI is a direct estimator of the absorbed fraction of photosynthetically active radiation and, indirectly, of aboveground net primary production (ANPP; Di Bella *et al.* 2004; Piñeiro *et al.* 2006). We estimated the following seven attributes that characterise aspects of phenology: date of the beginning of the growing season, date of the end of the growing season, duration of the growing season, date of occurrence of the maximum annual NDVI, maximum annual NDVI value, minimum annual NDVI value, annual NDVI integral (ANDVI) and amplitude. We also calculated the coefficient of inter-annual variation of NDVI (CV-NDVI) for each treatment. (Further details are presented in the Supplementary material.)

Data analysis

Analyses of botanical composition, cover, species richness and vegetation diversity among treatments were performed using one-way ANOVA. Model assumptions were explored and data transformations were used to meet these assumptions. The cover data of some species were log-transformed to meet the assumption of normality and homogeneity of variance of residuals. Seasonality parameters extracted from the fitted NDVI curves were compared by repeated-measures ANOVA over time ($n = 5$ years, 2013–2018), between treatments (1 pixel per 4 replicate × 3 treatment) and their interaction. The relationship between ANDVI and rainfall was analysed by simple Linear regression. In all cases, the significance level was $P < 0.05$ and Duncan's test was used as a *post hoc* test. Data from the conserved woodland were analysed only with descriptive statistics (mean and standard deviation). Analyses were performed with the statistical software InfoStat v. 2018 (Di Rienzo *et al.* 2018).

Results

Cover, botanical composition and diversity of vegetation functional groups

Shrub removal modified the cover of vegetation functional groups (Fig. 2). Tree cover was reduced in the roller-chopping and hand-cutting treatments ($P = 0.0001$), whereas the opposite was true for grass cover in the hand-cutting treatment ($P = 0.0041$; Fig. 2). Cover of dominant tree species, such as *Prosopis torquata* and *Prosopis flexuosa*, was lower in the cleared treatments than in degraded rangeland (Table 1). *Aspidosperma quebracho-blanco*, a tree species abundant in conserved woodland, was not recorded in any treatment (Table 1).

Shrub cover recovered following roller-chopping, but not hand-cutting ($P < 0.001$). Cover of the dominant shrub species, such as *Larrea divaricata*, *Cordobia argentea* (Griseb.) Nied. and *Mimozyganthus carinatus* in the roller-chopping was similar to that in degraded rangeland. These species were not recorded in the hand-cutting treatment, where dominant woody species were *Vachellia aroma* (Gillies ex Hook. & Arn.) Seigler & Ebinger and *Prosopis flexuosa* (Table 1).

Grass cover in the hand-cutting treatment was significantly higher than in degraded rangeland (Fig. 2), with *Cenchrus ciliaris* being the dominant species. Other dominant species were not recorded in the hand-cutting

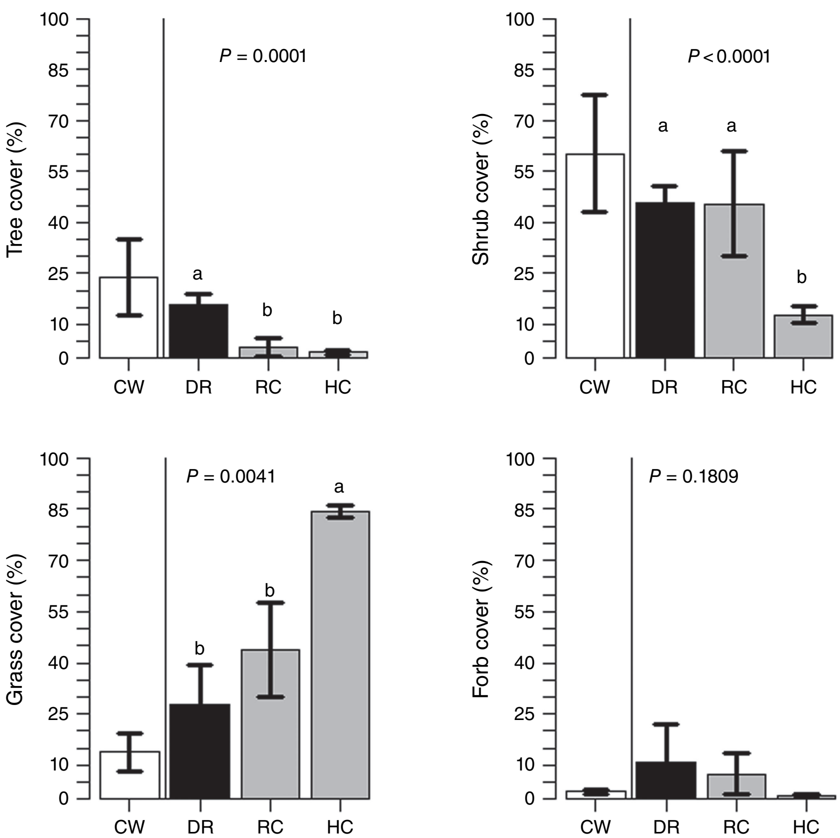

Fig. 2. Mean cover (%) of vegetation functional groups (trees, shrubs, grasses and forbs) for conserved woodland (CW), degraded rangeland (DR), roller-chopping (RC) and hand-cutting (HC). In the hand-cutting, the grass cover corresponds entirely to *Cenchrus ciliaris*. Different letters represent significant differences among treatments (at $P = 0.05$, Duncan's *post hoc* test). Conserved woodland was not subject to ANOVA. Bars indicate mean values and lines indicate standard deviation.

treatment (Table 1). Forb cover did not change significantly with shrub-removal treatments ($P = 0.1809$; Fig. 2).

Species richness and diversity were significantly ($P = 0.001$) higher in conserved woodland and lower in hand-cutting treatment, with degraded rangeland and roller-chopping treatments being indistinguishable from each other at intermediate levels (Fig. 3).

Seasonal dynamics of NDVI and phenology

Shrub-removal treatments modified the NDVI (Fig. 4*a*), and reduced ANDVI and the maximum and minimum NDVI values, most evidently in the hand-cutting treatment (Table 2). CV-NDVI was higher in the roller-chopping and hand-cutting treatments than in the degraded rangeland and conserved woodland (Table 2). The seasonal variation of

Table 1. Cover (mean ±s.d., %) of dominant species discriminated by vegetation functional group (trees, shrubs, grasses and forbs) for conserved woodland (CW), degraded rangeland (DR), roller-chopping (RC) and hand-cutting.

Species	Conserved woodland	Degraded rangeland	Roller-chopping	Hand-cutting	*P*-value
Trees					
Aspidosperma quebracho blanco Schltdl.	17.9 ± 3.8	0.0	0.0	0.0	0.0
Prosopis torquata (Cav. Ex Lag.) DC	6.0 ± 6.1	13.4 ± 2.1a	3.4 ± 2.7b	0.0c	<0.0001
Prosopis flexuosa DC.	1.8 ± 1.3	2.3 ± 1.6a	0.0b	1.8 ± 0.6a	0.0557
Shrubs					
Larrea divaricata Cav.	14.8 ± 6.4	15.7 ± 4.6a	16.9 ± 4.2a	0.0b	0.0001
Cordobia argentina (Griseb.) Nied.	8.4 ± 13.3	15.9 ± 9.4a	7.8 ± 9.5a,b	0.0b	0.0490
Mimozyganthus carinatus (Griseb.) Burkart	5.6 ± 8.7	0.6 ± 1.2b	3.1 ± 2.3a	0.0b	0.0365
Celtis chichape (Wedd.) Miq.	5.2 ± 5.2	0.7 ± 1.4	1.4 ± 1.7	1.2 ± 0.9	0.7681
Parkinsonia praecox (Ruiz & Pav. ex Hook.) Hawkins	4.7 ± 5.4	0.4 ± 0.7a,b	1.6 ± 1.3a	0.0b	0.0506
Vachellia aroma (Gillies ex Hook. & Arn.) Seigler & Ebinger	0.0	0.0b	0.4 ± 0.8b	9.4 ± 1.2a	0.0003
Grasses					
Leptochloa crinita (Lag.) P.M.Peterson & N.W.Snow	4.1 ± 3.0	11.2 ± 6.4a,b	4.4 ± 5.5a,b	0.0b	0.029
Setaria pampeana Parodi ex Nicora	3.3 ± 0.6	3.4 ± 0.6a	2.2 ± 2.8a,b	0.0b	0.021
Gouinea paraguayensis (Kuntze) Parodi	0.7 ± 0.8	4.3 ± 2.5a	4.7 ± 3.7a	0.0b	0.023
Cenchrus ciliaris L.	0.0	0.0c	20.1 ± 12b	84.3 ± 1.9a	0.000
Forbs					
Pseudabutilon virgatum (Cav.) Fryxell	0.7 ± 0.4	5.5 ± 3.9a	0.9 ± 0.7b	0.0b	0.020
Evolvulus arizonicus A.Gray	0.0	4.2 ± 6.5	0.3 ± 0.6	0.0	0.243
Sida argentina K.Schum.	0.4 ± 0.4	0.0	2.2 ± 3.5	1 ± 0.7	0.367

Different letters represent significant differences among treatments (at $P = 0.05$, Duncan's *post hoc* test). Conserved woodland was not subject to ANOVA.

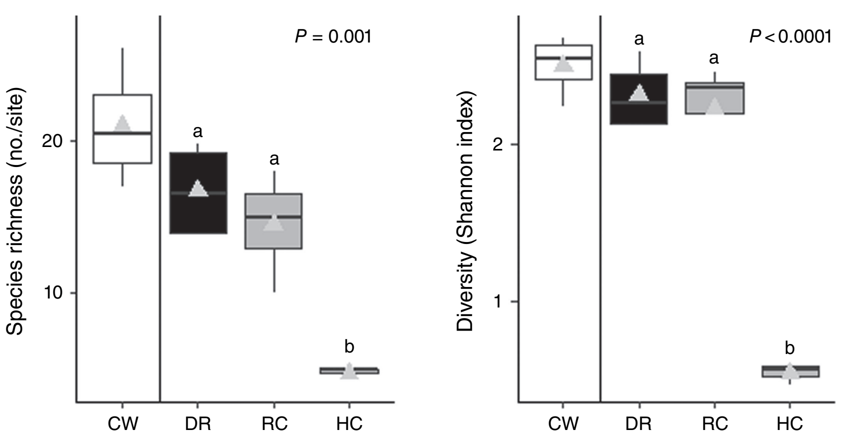

Fig. 3. Species richness and vegetation diversity for conserved woodland (CW), degraded rangeland (DR), roller-chopping (RC) and hand-cutting treatments. The solid lines inside the box represent the median, the triangles represent the mean value and the upper whisker is equal to the maximum value and the lower whisker is equal to the minimum value. The upper edge of the boxes is equal to the 95th quartile and the lower edge to the 5th quartile. Different letters represent significant differences among treatments (at $P = 0.05$, Duncan's *post hoc* test). Conserved woodland was not subject to ANOVA.

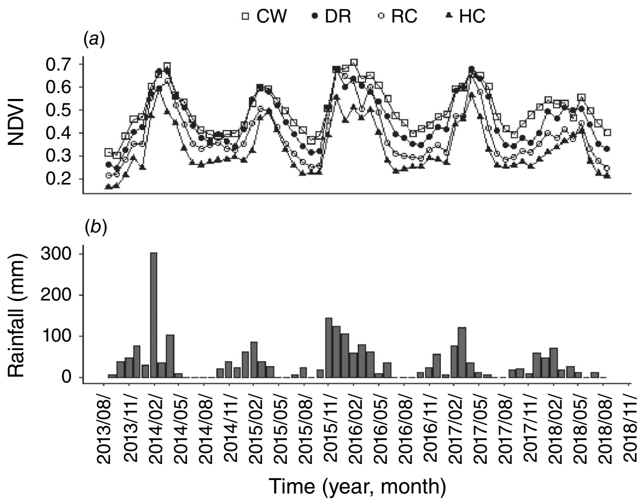

Fig. 4. (*a*) Normalised difference vegetation index (NDVI) dynamics, mean values for conserved woodland (CW), degraded rangeland (DR), roller-chopping (RC) and hand-cutting (HC) (period 2013–2018). (*b*) Monthly total rainfall for the period 2013–2018 (data obtained from the TRMM satellite of the Giovanni platform).

NDVI was associated with the seasonality of precipitation (Fig. 4*b*); so, the lowest NDVI values were mostly detected during 2014–2015 and 2017–2018, the least rainy periods during the 5 years of study. The analysis of the relationship between ANDVI and precipitation showed that both conserved woodland and degraded rangeland were more independent of this variable than were the roller-chopping and hand-cutting treatments (Fig. 5).

Discussion

Effects of shrub removal on vegetation structure and composition

Consistent with predictions, shrub removal modified vegetation functional diversity. Dominance changed from tree and shrub species to grasses and shrubs in the roller-chopping treatment, and to one dominated by more than 80% grass cover with hand-cutting. The high regeneration capacity of the shrub stratum and the low regeneration capacity of the tree stratum after the roller-chopping were consistent with results for shrubland sites in central Argentina (Steinaker *et al.* 2016). Roller-chopping damaged juvenile trees because it was unselective and only large, mature trees were retained (Navall 2008). In addition, the establishment of *C. ciliaris* probably increased competition with tree seedlings in early stages of natural regeneration (Kunst *et al.* 2012). Woody removal and grass augmentation can suppress tree seedling establishment (Monegi *et al.* 2022), and results suggest that a similar situation occurred, with tree seedlings exposed to increased grazing pressure (herbivory and trampling) as a result of intensification of grazing on disturbed areas.

Shrub cover substantially recovered following roller-chopping, but not hand-cutting. Species richness and vegetation diversity drastically declined under hand-cutting. Consequently, only species with seed banks or seedlings formed part of the secondary succession. In the Dry Chaco, basal regrowth is an important mechanism for woody species to form new aerial biomass, and could explain why shrub density was not reduced on roller-chopping compared with hand-cutting, where regeneration depends almost exclusively on the seed bank (Blanco *et al.* 2005; Marchesini 2011; Bravo *et al.* 2018). In the transition stage (5 years after shrub removal), shrub cover of species with regrowth capacity, such as *L. divaricata*, regained and even increased compared with woodland and degraded rangeland. However, when removed by the roots (hand-cutting), *L. divaricata* was replaced by *V. aroma*, a spinescent shrub that establishes mainly from seed.

Hand-cutting appeared more efficient than roller-chopping in reducing long-term (10 years) shrub populations. However, hand-cutting is less ecologically sustainable and could affect other essential ecosystem services beyond improving forage supply for livestock (Kunst *et al.* 2012). Unlike hand-cutting, roller-chopping incorporates substantial plant residues into the soil, increases soil moisture and allows more light to enter lower vegetation strata favouring grasses (Blanco *et al.* 2005; Kunst *et al.* 2012). This supports a need for strategies for selective deforestation and conservation management in the Dry Chaco to increase forage production and native woodland regeneration, as well as conservation of other ecosystem services (Boletta *et al.* 2006; Silberman *et al.* 2015).

Changes in the dynamics of NDVI (green biomass)

On the basis of the NDVI assessment, sites without shrub removal had a higher green biomass than those with shrub removal, and the conserved woodland had the highest values of green biomass. NDVI considers only the green vegetation fraction; so, by including the non-photosynthetic fraction (branches, woody stems, etc.), the differences in the biomass of these sites would be even greater (Marchesini 2011). ANDVI values observed with roller-chopping and hand-cutting treatments could be a consequence of reduction in functional diversity. Greater functional diversity has been positively related to green biomass, ANPP and carbon sequestration (Díaz and Cabido 2001; Flombaum and Sala 2008). In Dry Chaco woodland, historic tree removal, together with increased shrubs, reduced native grasses and caused ecosystem impoverishment (Marchesini 2011). Trees absorb more radiation and more efficiently convert it to primary production than do many perennial grasses (Blanco 2017). Although replacing native vegetation with grasses allows for a higher harvestable

Table 2. Mean (±s.d.) values of phenological attributes estimated from the NDVI seasonal trend (period 2013–2018) for conserved woodland (CW), degraded rangeland (DR), roller-chopping (RC) and hand-cutting.

Item	Conserved woodland	Degraded rangeland	Roller-chopping	Hand-cutting	*P*-value
Annual integral NDVI	5.41 ± 0.76	4.93 ± 0.51a	4.19 ± 0.65b	3.43 ± 0.6c	Treatment (<0.0002) Year (0.0001) Interaction (<0.001)
Start of growing season	27 Oct. ± 32 days	25 Oct. ± 37 days	28 Oct. ± 44 days	06 Nov. ± 48 days	Treatment (0.6046) Year (<0.0001) Interaction (0.6782)
End of growing season	01 July ± 15 days	23 June ± 26 daysa	7 June ± 20 daysb	01 May ± 12 daysc	Treatment (0.0005) Year (<0.0001) Interaction (0.093)
Length of growing season	274 ± 25 days	265 ± 32 days	250 ± 42 days	225 ± 40 days	Treatment (0.0794) Year (0.0506) Interaction (0.3584)
Date NDVI maximum	18 Mar. ± 34 days	18 Mar. ± 33 days	15 Mar. ± 38 days	23 Mar. ± 31 days	Treatment (0.4743) Year (<0.0001) Interaction (0.1703)
Max. annual NDVI	0.63 ± 0.07	0.61 ± 0.07a	0.55 ± 0.1b	0.48 ± 0.09c	Treatment (0.0011) Year (0.0413) Interaction (0.0078)
Min. annual NDVI	0.38 ± 0.03	0.33 ± 0.02a	0.28 ± 0.01b	0.23 ± 0.02c	Treatment (<0.0001) Year (0.0004) Interaction (0.0896)
Amplitude		0.28 ± 0.01	0.27 ± 0.01	0.25 ± 0.01	Treatment (0.2628) Year (0.0368) Interaction (0.0072)
Coefficient of variation of NDVI (%)	6	5	10	12	

Different letters represent significant differences among treatments (at $P = 0.05$). Conserved woodland was not subject to ANOVA.

fraction of ANPP, its total value is reduced compared with natural systems, especially native woodland (Rueda *et al.* 2013). Our results showed that shrub-removal treatments and *C. ciliaris* seeding maintain total vegetation cover and increase forage supply for livestock, but do not compensate for the loss of green biomass, which could also translate into lower ANPP. In this sense, the manual clearance treatment could maintain a low proportion of woody species and a high proportion of grasses in the long term, although always with a lower green biomass than in natural sites.

NDVI analysis showed that sites with a higher proportion of woody species (conserved woodland and degraded woodland) had higher values of NDVI and a lower CV-NDVI than did the sites that had been roller-chopped and hand-cut. Consistent with the findings of Marchesini (2011) and Steinaker *et al.* (2016), shrub removal reduced the growth period, ANDVI, and maximum and minimum NDVI, probably because shrubs and trees generally have a longer growing season than do herbaceous species (Blanco 2017). The greater stability in NDVI dynamics found in the conserved woodland and the degraded rangeland may be related to a lower dependence on rainfall (Zerda and Tiedemann 2010). Woody species are generally more independent of rainfall, because they have deep roots with access to water in the lower soil horizons, whereas grasses, with shallow roots, experience growth pulses linked to rainfall and soil moisture in the upper horizons (Schwinning and Sala 2004; Villagra *et al.* 2011). Thus, the greater the structural difference between native vegetation (conserved woodland or degraded rangeland) and its replaced vegetation, the greater the functional changes in the ecosystem, particularly those linked to carbon and water cycling (Volante *et al.* 2012;

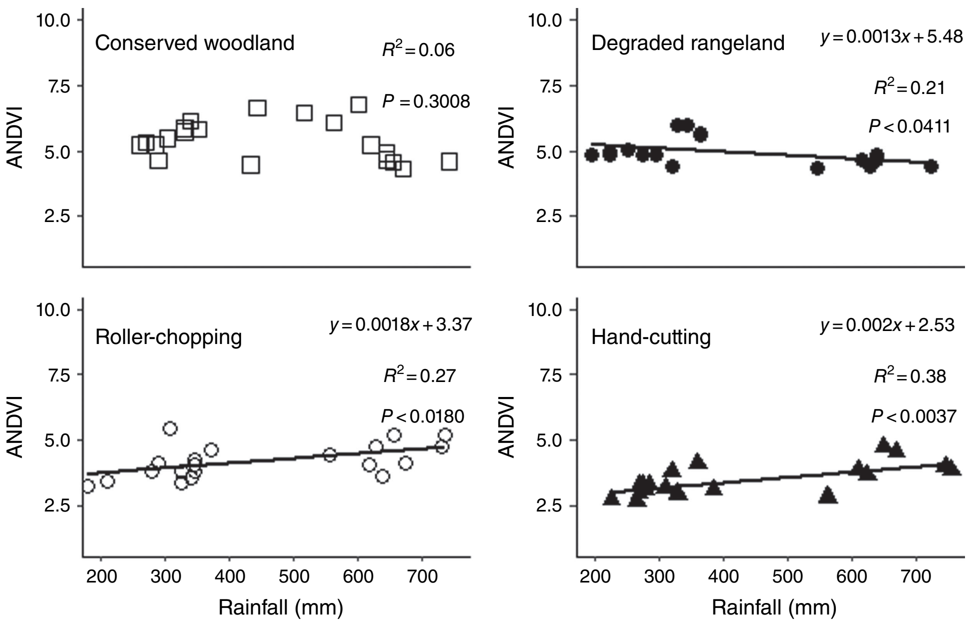

Fig. 5. Linear regression between annual integral of NDVI (ANDVI, integrated from September to August) and total annual rainfall (accumulated from September to August) for conserved woodland (CW), degraded rangeland (DR), roller-chopping (RC) and hand-cutting (period 2013/2018).

Steinaker *et al.* 2016; Magliano *et al.* 2017). Ultimately, a more even distribution of green biomass throughout the year confers greater stability of forage for primary consumers, so that systems dominated by woody species could be playing a key role in ecosystem-service conservation (Volante *et al.* 2012).

Conclusions

Shrub removal and the seeding of *C. ciliaris* increased forage available for animal production, but decreased green biomass and modified seasonal dynamics. Grass-dominated systems may be less stable and more dependent on rainfall than are tree-dominated systems, and also provide a different functional diversity because of their structure. Responses also depended on the intensity of shrub-removal disturbance. Roller-chopping is a more conservative practice than is manual bush clearance, because it maintains high levels of vegetation functional diversity and forage production. However, maintaining tree regeneration is important, and because both types of disturbance affect this process, there was no evidence of transitions to desirable conservation states that make environmental conservation (ecosystem services) and livestock production compatible, as might be the case in woodlands. This study has highlighted the importance of designing selective vegetation interventions compatible with the maintenance of functional diversity, tree regeneration and increased forage production.

Supplementary material

Supplementary material is available online.

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